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MK 82 BOMB EJECTION SENSITIVITY TEST REPORT

by

Donald R. Barr

and

F. Russell Richards

February 1979

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An analysis of the data obtained in the Bomb Ejection Sensitivity Tests, conducted at White Sands during the summer of 1978, is presented. Preliminary reduction of the data was performed by the Marine Aviation Detachment at Point Mugu, California. It is concluded that rack position had significant effects on bomb impact means during these tests. The effects of bomb rack positions increases CEP about 50 percent over what could be expected if those effects were not present.

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ABSTRACT

An analysis of the data obtained in the Bomb Ejection Sensitivity Tests, conducted at White Sands during the summer of 1978, is presented. Preliminary reduction of the data was performed by the Marine Aviation Detachment at Point Mugu, California. It is concluded that rack position had significant effects on bomb impact means during these tests. The effects of bomb rack positions increases CEP about 50 percent over what could be expected if those effects were not present.

1. Introduction

At the TPQ-27 PSVT planning meeting held in Monterey on 19 January 1978, a question arose concerning whether the rack position of a bomb affected its dispersion and expected impact point relative to the target. At that time it was suggested that an experiment of modest size could be performed which would provide an answer to this question. Additional background and experimental design considerations are given in Reference 1.

Test drops were conducted at White Sands, N.M. during the summer of 1978. The raw data obtained in this experiment were reduced by MAD at Point Mugu, California. A description of this reduction process is given in Reference 2. Briefly, the process consisted of combining aircraft track and position data from several sensors (including phototheodolites, an ARIS pod, a radar system and a laser tracking system), in order to obtain estimates of aircraft velocity and acceleration components at the time of drop of each bomb. In addition, wind at altitude was measured for each of the 10 sorties, with 8 drops planned for each sortie. The weight of each bomb was recorded. Using a MAD algorithm based on bomb ballistic tables provided by NWC, Dahlgren, a predicted point of impact for each bomb was determined, and the actual point of impact was located relative to the predicted point, in coordinates oriented with + Y along the aircraft track and + X perpendicular to the right of aircraft track. The origin of the coordinate system is predicted impact point.

The bombs were dropped one at a time, under nearly identical drop conditions; nominal values (which varied somewhat from drop to drop) were:

aircraft heading:	190° from true North
aircraft speed:	450 KTAS
altitude:	10,000 feet AGL
bomb weight:	500 lbs
aircraft acceleration:	straight and level, constant speed.

Of the 80 bombs dropped (10 sortees × 8 bombs per sortie), data on 65 were ultimately transferred to us from the reduction process at MAD. The "lost" cases occurred through a variety of causes, which in our opinion do not provide reason for serious concern that the "surviving" cases represent a biased sample or that they are otherwise non-representative. The bombs were dropped in the same sequence within each sortie, labeled 1-8 in Figure 1. All sorties were flown with A4 aircraft. The data which were used in our analysis are reproduced in Appendix 1. A variety of analyses were performed on these data, and the results are described in Section 3 of this report. A summary of the results of the analyses is presented in the next section.

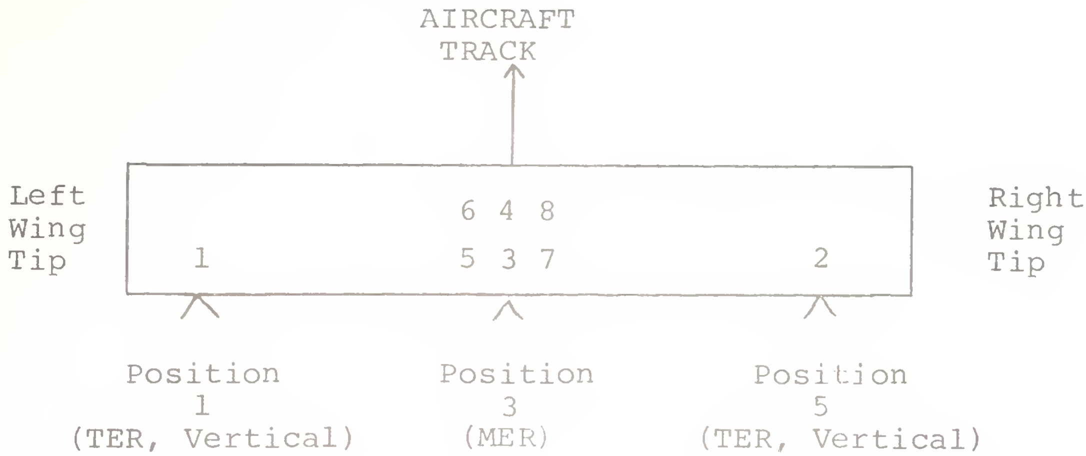

FIGURE 1. Bomb rack positions, in order of drop within a sortie.

2. Summary of Analysis Results

The significance of the following effects were tested using analysis of covariance:

Bomb weight

Aircraft velocity components (V_X, V_Y, V_Z)

Altitude

Wind Components at altitude (W_X,W_Y)

Speed

Rack Position

Sortie.

Individual Analyses were conducted for range (Y) and cross-range (X) data. (Note this is not the same coordinate system as for V_X, V_Y, etc.)

- Of the above effects and factors, only rack position is statistically significant. It is significant for both X and Y.

- Multiple comparisons of means for rack positions show that: for X, positions 6, 5, 4, 1 are significantly to the left of 3, 2, 7, 8;
  for Y, 1 is significantly shorter than 8, 6, 4, 3, 7, 5.

- The increase in CEP due to rack position effects is 50%.

- Overall bias is significant. (The MPI was 72 feet short and 37.5 feet left of the predicted impact point.)

3. Analyses and Results

Analyses of covariance (AOC) were conducted with X data and Y data (cross-range "miss" and range "miss," respectively). Rack position (at 8 levels) and sortie (at 10 levels) were included as factors. Bomb weight, V_X, V_Y, V_Z, altitude, $wind_X$, $wind_Y$, and speed were included as covariates. Normality and equal variance assumptions appeared to be tenable, based on examination of plots of impact points. (For example, the data for each position give estimates of variance which pass the F_{max} test with $\alpha = .05$). Since the design is not orthogonal, the order of removing effects for the reduced models used in computing the AOC tables might, in theory, have some effect on the results and their interpretation. However, from a practical point of view, the "degree" of non-orthogonality is slight, and we believe the individual tests we performed are not difficult to interpret.

Among all of the factors and covariates we tested, only rack position was statistically significant. An analysis of variance table is shown for rack position for X and Y data in Figure 2.

Pairwise comparisons were made on rack position means. The AOC shows there is a difference due to rack positions; the pairwise comparison shows which positions or groups of positions are alike and which are different. We used Tukey's method of

X DATA--RACK POSITION EFFECT

ANOVA TABLE

Source	DF	SS	MS	F
Treatment	7	251858.33	35979.76	19.49**
Error	57	105224.05	1846.04	
TOTAL	64	357082.38		

Y DATA--RACK POSITION EFFECT

ANOVA TABLE

Source	DF	SS	MS	F
Treatment	7	79628.86	11375.55	3.97**
Error	57	163382.76	2866.36	
Total	64	243011.62		

"**" means "significant at the $\alpha = .01$ level," or, practically speaking, "very significant."

FIGURE 2: Analysis of Covariance Tables
Bomb Ejection Sensitivity Tests
(N = 65).

multiple comparisons, even though sample sizes vary somewhat from one position to another (for example, there were 6 data for position 1 and 10 for position 3). The significance of values obtained for differences between rack position means, shown in Figure 3, were unambiguous even with the 6 to 10 variation in sample sizes (values of HSD shown in Figure 3 are the critical values for $\alpha = .05$). The means of Y data shown in Figure 3 are listed in order of decreasing shortness (in feet); those for X data in order of decreasing leftness. For example, rack position 1 produced the shortest mean, at 164.6 feet short of the predicted range; position 6 gave the mean left most of the predicted impact at 120.2 feet left. Asterisks in Figure 3 indicate significance at the $\alpha = .05$ level. From these tests we conclude:

- position 1 gave impacts significantly shorter than positions 6, 4, 3, 7, 5.
- There were not significant differences in shortness among the other positions.
- Positions 6, 5 as a group produced impact significantly to the left of positions 3, 2, 7, 8. Positions 4 and 1 had means significantly to the left of 2, 7, 8.
- There were not significant differences in cross-range bias for positions 6, 5, 4, 1 or for positions 3, 2, 7, 8.

Y-DATA

Position:Mean	Pos → 2	8	6	4	3	7	5
1:-164.6	65.2	87.0?	98.7*	98.8*	110.7*	125.4*	126.7*
2:- 99.4		21.8	33.5	33.6	45.5	60.2	61.5
8:- 77.6			11.7	11.8	23.7	38.4	39.7
6:- 65.9				.1	12.0	26.7	28.0
4:- 65.8					11.9	26.6	27.9
3:- 53.9						14.7	16.0
7:- 39.2							1.3
5:- 37.9							

(HSD = 93 FOR α = .05)

X-DATA

Position:Mean	Pos → 5	4	1	3	2	7	8
6:-120.2	.6	46	66.9	89.8*	147.3*	154.2*	160.5*
5:-119.6		45.4	66.3	89.2*	146.7*	153.6*	159.9*
4:- 74.2			20.9	43.8	101.3*	108.2*	114.5*
1:- 53.3				22.9	80.4*	87.3*	93.6*
3:- 30.4					57.5	64.4	70.7?
2: 27.1						69	13.2
7: 34.0							6.3
8: 40.3							

(HSD = 75.0 for α = .05)

FIGURE 3: Tukey's Multiple Comparisons: Differences and Significance Bomb Ejection Sensitivity Tests; N = 65

CEP's were computed using an estimator based on the parametric "circular normal" model. The values obtained agree quite well with nonparametric "sample median" based estimates, which we do not report here. We estimated CEP measures from the respective mean points of impact in all cases, since there is significant bias (in range and cross-range) relative to the predicted impact points. We estimated CEP by means of the expression

$$CEP = \sqrt{(.6931\overline{R^2})\ N/(N-1)}$$

where

$\overline{R^2}$ is the average of the squared radial distances from MPI to impact points, and

N is the sample size for the given data set (rack position, etc.).

A summary of estimated CEP's and means (all in feet) for data from each rack position is shown in Figure 4. The overall CEP was computed using all data with the overall MPI (65 radial miss distances). The pooled CEP was computed with $\overline{R^2}$ obtained by adding, for all positions, the squares of radial miss distances from respective MPI's and dividing by the appropriate degree of freedom. The percent increase was calculated as

$$100 \times (\text{overall CEP} - \text{pooled CEP})/\text{pooled CEP}\ .$$

Rack Position	CEP	N	XBAR	YBAR
1	46.5	6	- 53.3	-164.6
2	54.4	8	27.1	- 99.4
3	88.4	10	- 30.4	- 53.9
4	88.8	8	- 74.2	- 65.8
5	46.8	9	-119.6	- 37.9
6	38.5	8	-120.2	- 65.9
7	46.2	7	34.0	- 39.2
8	40.8	9	40.3	- 77.6
Overall CEP	81.2	65	- 37.5	- 72.1
Pooled CEP	54.4			

Increase due to positions = 49.5 percent

FIGURE 4: CEP Analysis

Bomb Ejection Sensitivity Analysis Tests

(N = 65).

A plot of the means (numbered by rack position) and CEP's (circles with center at MPI and radius CEP) is shown in Figure 5. Note positions 3 and 4 gave the largest estimated CEP's, and there is nearly symmetry between CEP's for left positions and the corresponding right positions. For example, positions 5 and 7 have nearly the same estimated CEP's; similarly for positions 6 and 8. Note also that the smallest estimated CEP, 38.5 at position 6, is consistent with the scatter one would expect due to ballistic dispersion alone with a 3.5 mil bomb.

4. Conclusions and Recommendations

As we indicated in the summary of results, there is little doubt that rack positions affected (were associated with differences in) MPI's. The effect is, predictably, most apparent in the cross-range direction. There is also little doubt the mean of the drops as a whole falls short and to the left of the predicted impact points. We call this "system bias," although it is not possible to determine whether this tendency is due to the bomb dropping system (including bombs, aircraft and atmosphere), whether it is due to the tracking systems, or whether it is due to the method used to calculate predicted impact points. Of course, the apparent bias might be due to a combination of factors from these sources.

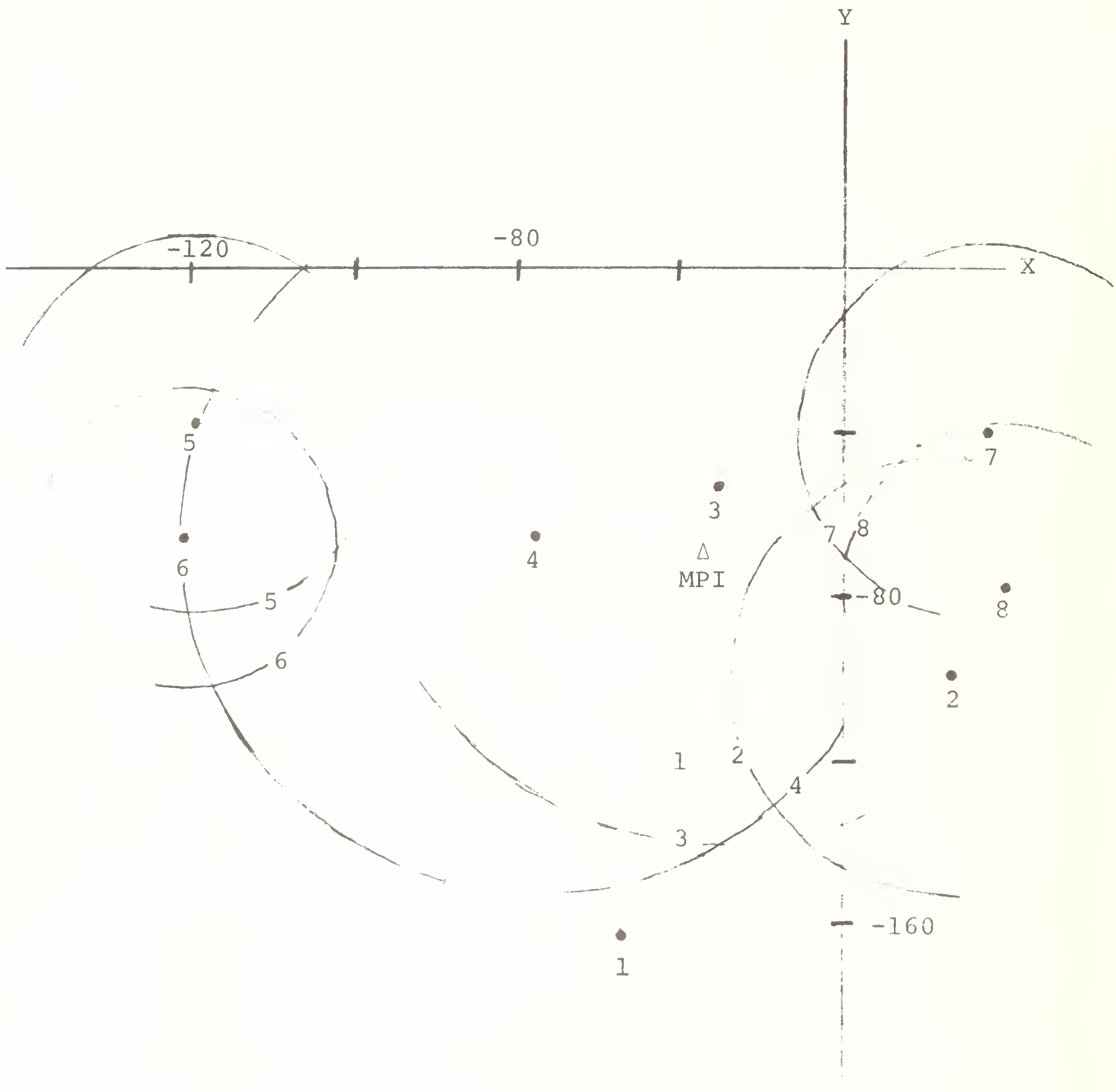

FIGURE 5. Rack position means and CEP's Bomb Ejection Sensitivity Test Data (N = 65).

Because of apparent system bias, we have calculated CEP's using miss distances measured from corresponding MPI's. If the distances were measured from the origin of the coordinate system (the "target"), the CEP's would, of course, be much larger. The reader should keep in mind, therefore, that the CEP estimates reported here for each rack position represent a "best case," optimistic situation. These CEP's would be appropriate for weaponeering applications only if both the system bias and the rack effects were accounted for and eliminated in the TPQ-27 software. In such a case, the "pooled CEP," 54.4 ft, would be our current estimate of the best overall CEP attainable under the conditions of this test. If only system bias were accounted for, the "overall CEP," 81.2 ft, would be our estimate of the best CEP attainable.

There is evidence in the data, and the physical phenomena and procedure producing them, which suggest possible "causes" of the system bias. For example, if the bomb ejection velocity used in prediction of impact points were increased, the MPI would move longer; thus ejection velocity is a potential "parameter" to modify in order to "explain" the short hits. (Of course, there are alternate potential explanations of the short hits, including drag coefficients, bomb weights, etc.).

It has been suggested the leftward bias observed in these drops may be (at least in part) due to bomb spin. A clockwise spin (as viewed from behind the bomb) would tend to cause a leftward drift in the bomb. Similarly, the Coriolis effect would tend to cause a leftward "bias," if not accounted for, since all drops in this test were made with essentially a southward aircraft heading. According to Reference 2, neither bomb spin nor Coriolis effects were accounted for in computing the predicted impact points. It is possible that their incorporation into the predictions would substantially change the left-bias we observed.

We believe it is reasonable to change parameters in the TPQ-27 software, or to incorporate heretofore unaccounted effects, provided there is a very credible physical or engineering explanation for such changes. However, we believe making such changes, solely because they will tend to remove bias, is a very dangerous way to proceed. If such "parameter tweeking" is necessary to remove bias under the present drop conditions, might it not be necessary to make different changes for other drop conditions? Without satisfactory physical explanation of effects of changes, there is reason to expect one would have to "calibrate" the system (via parameter tweeking) over many combinations of drop conditions, using drop data to "adjust" the MPI on the target somewhat like in artillery adjustment. Obviously this would be enormously expensive.

We therefore suggest that changes to the TPQ-27 software or input parameters be made only when there is physical explanation for why it is desirable. Perhaps bomb spin correction is of this nature, whereas bomb drag coefficient change may not be.

REFERENCES

1. D. R. Barr, "Possible Approaches to Determining Lateral and Range Effects of Bomb Stations, Based on Observed Impact Points," Naval Postgraduate School Technical Report NPS55-78-10, 1978.

2. Letter from Commanding Officer, MAD, Point Mugu, California, to Superintendent, Naval Postgraduate School (NPS55-Bn), Monterey, Ca. (3A:RLW:lmb,13530, 3 Jan 1979); Subj: MK 82 Bomb Ejection Sensitivity Test.

APPENDIX

Data used for this report ($N = 65$) were obtained in the MK 82 bomb ejection sensitivity test drops made at White Sands during the summer of 1978. The first stage data reduction, involving estimation of aircraft trajectories at times of drop and prediction of bomb impact points, was performed by MAD at Point Mugu, California. All distance data are in feet and velocities are in feet per second. Wind components (W_X and W_Y) are the negative of projections of the wind at altitude vector on the aircraft track. The following symbols head the data columns:

Y = range miss

X = cross-range miss

B = bomb weight (pounds)

(V_X, V_Y, V_Z) = estimated velocity vector of aircraft

A = altitude (feet above ground level) $\times 10^{-2}$

(W_X, W_Y) = wind at altitude vector in negative aircraft heading coordinates

SPD = speed

P = rack position

S = sortie number.

Y	X	B	VX	VY	VZ	ALT	VX	VY	SP[illegible]		
¯217.4	¯91.9	497.1	¯154.5	¯743.2	¯1.2	102.5	3.5	22.7	759.1	1	1
¯20.3	¯39.7	503.2	¯164.8	¯752.4	¯0.9	102.6	3.2	22.7	770.2	3	1
¯62.4	¯32.1	497.0	¯174.8	¯755.1	¯4.9	102.7	2.9	22.8	775.[illegible]	4	1
¯132.5	¯176.9	500.4	¯152.2	¯727.7	20.3	102.7	3.4	22.7	743.4	[illegible]	1
¯89.8	58.4	502.2	¯169.8	¯746.5	7.6	102.1	3.0	22.8	765.6	[illegible]	1
¯74.0	33.2	479.6	¯152.9	¯740.9	¯21.8	99.7	¯1.4	9.[illegible]	756.[illegible]	2	2
¯23.7	¯19.2	502.9	¯134.1	¯720.2	¯3.0	98.9	¯1.2	9.9	732.[illegible]	[illegible]	[illegible]
¯2.7	¯51.8	498.4	¯117.0	¯718.7	¯3.9	98.6	¯1.0	9.9	728.1	4	2
6.1	¯145.1	495.0	¯138.6	¯742.4	¯6.7	99.9	¯1.2	[illegible].3	755.3	5	2
¯72.4	¯125.7	503.0	¯150.0	¯753.7	¯3.5	99.1	¯1.4	9.9	768.5	[illegible]	[illegible]
¯59.0	¯3.6	499.4	¯141.1	¯751.1	¯8.9	99.1	¯1.3	9.9	764.2	8	2
¯115.9	¯43.0	498.0	¯115.3	¯770.0	3.0	100.0	¯17.5	¯3.6	773.6	1	[illegible]
¯114.6	104.1	493.2	¯133.1	¯749.5	¯7.1	99.3	¯17.2	¯4.[illegible]	767.[illegible]	[illegible]	[illegible]
¯43.5	3.8	502.9	¯135.3	¯774.8	¯7.9	[illegible]	¯17.4	¯4.1	7[illegible].5	[illegible]	[illegible]
¯42.3	¯7.9	505.6	¯160.8	¯766.9	3.0	99.6	¯17.3	¯4.7	7[illegible].6	4	[illegible]
¯54.5	¯97.8	504.5	¯134.2	¯780.4	6.7	99.6	¯17.4	¯4.6	791.[illegible]	5	[illegible]
¯66.2	¯106.9	498.2	¯128.3	¯769.6	¯4.7	99.4	¯17.4	¯3.9	780.2	[illegible]	[illegible]
20.6	44.0	504.5	¯117.4	¯760.8	¯11.0	99.4	¯17.5	¯3.7	7[illegible]	7	[illegible]
¯109.6	61.8	500.8	¯133.0	¯753.9	3.2	99.6	¯17.4	¯4.1	775.4	[illegible]	[illegible]
¯206.0	¯25.8	496.6	¯183.9	¯716.5	12.5	100.2	¯23.5	¯5.2	73[illegible].7	1	[illegible]
¯51.0	35.0	500.6	¯126.7	¯757.5	2.3	99.5	¯23.9	¯3.2	75[illegible].0	[illegible]	4
¯84.5	¯9.0	499.3	¯107.9	¯769.7	¯10.9	99.4	¯24.0	¯2.5	777.[illegible]	[illegible]	4
¯42.5	¯86.0	502.9	¯123.2	¯748.5	12.2	99.1	¯23.9	¯3.1	753.6	5	4
¯69.3	97.7	500.7	¯108.5	¯740.9	¯6.2	99.4	¯24.0	¯2.7	748.[illegible]	[illegible]	[illegible]
¯30.2	¯57.6	499.7	¯132.2	¯744.6	¯19.6	99.6	¯3.0	11.8	75[illegible].2	[illegible]	5
25.7	1.4	506.3	¯152.9	¯743.9	¯3.0	99.2	¯3.3	11.7	75[illegible].4	4	
¯108.8	138.3	504.4	¯160.0	¯750.0	3.0	99.3	¯3.4	11.7	76[illegible].6	[illegible]	[illegible]
¯9.0	37.2	503.7	¯143.5	¯745.6	¯0.8	99.5	¯3.2	11.7	759.[illegible]	7	[illegible]
¯1.5	22.3	501.4	¯150.0	¯742.0	[illegible].7	99.4	¯3.[illegible]	11.7	757.[illegible]	[illegible]	[illegible]
¯151.9	¯33.9	503.5	¯144.7	¯740.2	[illegible].4	99.4	¯2.[illegible]	15.1	754.2	2	
¯116.8	¯35.5	500.4	¯155.9	¯746.2	¯1.3	99.9	¯3.6	15.1	762.3	[illegible]	[illegible]
¯118.6	¯117.0	497.7	¯153.6	¯740.1	¯6.4	[illegible]	¯3.6	15.1	755.[illegible]	4	[illegible]
¯32.6	¯100.0	504.8	¯136.4	¯742.4	¯10.7	99.5	¯2.7	15.2	754.[illegible]	[illegible]	
¯83.8	¯118.0	499.1	¯126.7	¯733.5	22.7	99.7	¯2.5	15.2	744.4	[illegible]	[illegible]
¯14.8	43.1	503.9	¯120.8	¯723.2	4.9	99.1	¯2.4	15.2	7[illegible].3	7	
¯83.4	46.9	507.0	¯128.5	¯734.9	¯19.4	99.8	¯2.5	15.2	746.1	[illegible]	[illegible]
¯187.4	¯47.4	501.1	¯141.7	¯738.3	¯10.3	99.3	2.1	12.5	751.[illegible]	1	7
¯83.1	16.0	497.5	¯148.5	¯741.6	5.9	100.0	2.0	12.5	756.3	[illegible]	7
¯217.1	¯151.1	508.1	¯128.4	¯750.1	¯17.7	99.[illegible]	2.3	12.5	751.[illegible]	[illegible]	7
¯197.7	¯191.9	500.4	¯124.6	¯746.1	¯0.3	100.3	2.4	12.5	758.[illegible]	4	[illegible]
¯18.3	¯112.5	503.1	¯131.9	¯731.4	¯19.4	99.6	2.2	12.[illegible]	743.2	[illegible]	[illegible]
¯69.6	¯100.1	496.5	¯147.0	¯730.9	5.0	99.7	2.[illegible]	12.5	745.5	[illegible]	[illegible]
¯42.7	26.1	499.5	¯136.6	¯740.4	¯13.1	99.2	2.2	12.5	752.9	7	7
¯63.4	29.0	500.0	¯135.8	¯731.0	5.3	99.[illegible]	2.2	12.5	743.5	[illegible]	[illegible]
¯150.3	¯50.3	500.1	¯131.1	¯732.4	1.3	100.2	2.[illegible]	12.5	744.[illegible]	1	[illegible]
¯169.1	¯25.1	500.1	¯129.0	¯738.9	¯0.3	100.4	2.3	12.5	750.1	[illegible]	[illegible]
88.1	97.7	499.7	¯113.4	¯758.2	¯15.9	99.5	2.5	12.4	767.6	3	[illegible]
¯26.6	¯129.7	504.2	¯136.7	¯734.7	¯5.1	100.7	2.2	12.[illegible]	747.5	[illegible]	[illegible]
¯96.1	¯42.6	495.5	¯132.5	¯751.3	¯23.6	99.6	2.3	12.5	752.[illegible]	[illegible]	
¯57.7	39.9	502.5	¯126.3	¯745.2	6.6	99.8	2.4	12.5	755.9	7	[illegible]

Y	X	B	VX	VY	VZ	ALT	WX	WY	SPD	P	S
¯98.5	23.2	505.3	¯143.0	¯751.5	¯2.9	99.2	2.1	12.5	765.0	8	8
¯110.4	¯61.2	500.1	¯139.7	¯749.6	2.3	99.6	0.7	5.5	762.5	1	9
¯86.8	60.0	500.8	¯136.2	¯757.3	1.2	99.6	0.7	5.5	769.4	2	9
¯56.5	¯21.7	511.8	¯141.5	¯739.1	¯7.6	99.6	0.7	5.5	752.5	3	9
¯40.2	¯41.2	503.2	¯140.8	¯745.0	¯0.7	99.5	0.7	5.5	753.2	4	9
¯59.1	¯135.4	500.6	¯127.0	¯746.9	1.1	99.9	0.8	5.5	757.5	5	9
¯37.0	¯129.9	504.6	¯142.3	¯743.1	3.1	99.7	0.7	5.5	756.5	6	9
¯33.6	36.5	499.0	¯136.9	¯733.4	¯2.7	99.7	0.7	5.5	746.1	7	9
¯123.4	27.1	492.0	¯142.9	¯743.4	13.3	99.5	0.7	5.5	757.0	8	9
¯64.5	26.7	494.8	¯131.4	¯763.7	¯4.0	100.2	5.6	¯1.3	774.9	2	10
¯32.2	¯76.1	500.1	¯155.1	¯746.1	17.1	100.6	5.6	¯1.1	762.1	3	10
¯88.2	¯153.4	498.6	¯155.9	¯758.0	¯1.2	100.4	5.6	¯1.1	773.9	4	10
19.0	¯92.9	499.9	¯135.6	¯762.4	¯5.8	99.3	5.6	¯1.2	774.4	5	10
12.7	¯150.2	502.1	¯118.6	¯748.3	1.3	99.3	5.6	¯1.3	757.7	[illegible]	10
¯136.9	11.2	503.4	¯163.1	¯738.3	16.3	99.0	5.7	¯1.0	756.1	7	10

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